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Strain Field Profiling with Energy Dispersive X-Ray Scattering

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Manufacture, or processing creates a residual strain (RS) distribution in a structural component that can dramatically alter load capacity and resistance to failure. There is unfortunately a dearth of methods to nondestructively depth-profile RS distributions in the important 0.01 to 10 mm range. We have been working on implementing energy disperssive x-ray diffraction (EDXRD) methods for RS depth profiling over this range. In EDXRD the incident/diffracted beam and sampling volume are fixed, and very stable (see Figure 1), while the sample is scanned through the scattering micro-volume. The Bragg reflection energies (E) and the inter-atomic-plane spacing (d_{hkl}) are related by E(keV) = 6.199/ d_{hkl} sin(θ) where 2θ is the constant scattering angle. The strain profile, given by the variation in the atomic spacing ($\Delta d_{hkl}/ d_{hkl}$), was determined by careful fitting of many lines in the diffraction spectra (see Figure 2).

A representative RS profile, for a 4130 steel blank, (see Figure 3) shows cold-rolling-induced interior-compressive and surface-tensile strains. The strain profile of the specimen, under cantilever bending, shows a linear elastic strain variation, from compression to tension, superimposed with the RS distribution. Clear evidence for CS-stress-induced plastic deformation (propagating inward from the CS-tensile-surface) can be seen in the compressive changes in the RS profile “after” the stress is released (highlighted by red arrows). To maintain equilibrium balancing tensile stains appear in the “after” RS distribution below the plastic zone (highlighted by blue arrows).

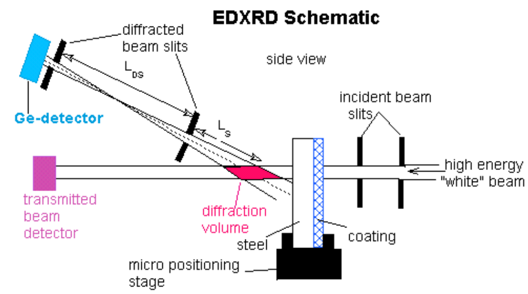

Figure 1. Experimental schematic (X17B1 at NSLS). The important incident and scattered beam collimating slits define the scattering micro-volume (grossly exaggerated in size for clarity). The sample is micro-swept through this scattering volume while the EDXRD spectra are collected by the energy-dispersive-Ge detector. A transmitted beam intensity monitor is useful in micro positioning materials to surfaces, defects and cracks.

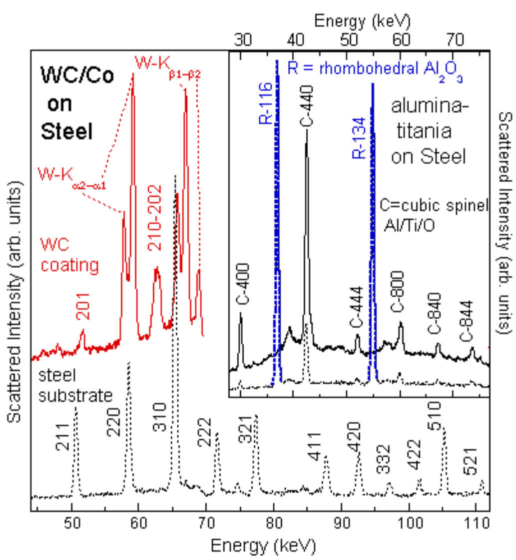

Figure 2(left). EDXRD spectra for the steel and WC-coating potions of composite specimen. Inset shows similar spectra for an alumina-titania coating on steel with varying mixtures of cubic (C) and rhombohedral (R) Al_2O_3 phases.

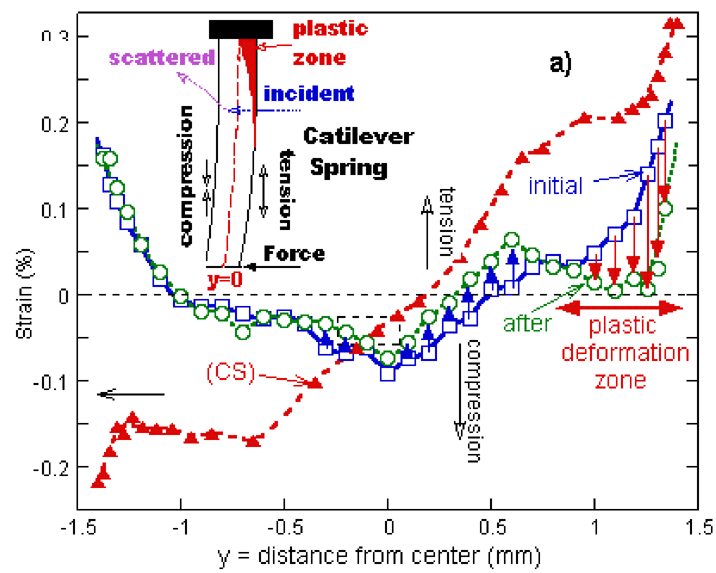

Figure 3(right). Strain profiles across a steel blank in its "initial", cantilever spring "CS" stressed, and "after" states. Note the plastic deformation zone and changes highlighted in red. Inset: CS schematic.